Energies and Radiative Transition Parameters for Mg-Like Tungsten

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By applying AUTOSTRUCTURE code, the energies and transitions for allowed (E1) and forbidden (E2, M1, and M2) lines for low-lying configurations in magnesium-like tungsten (W^{62+}) are studied. The electron correlation and relativistic effects are included in computations. Good agreement between our results and available other results are found. The data for E2, M1 and M2 besides some E1 transitions for low-lying levels are presented for the first time.

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1. Introduction

Tungsten ($Z = 74$) has become a center of focus of fusion research, being a main candidate for plasma-facing components [1]. In order for the plasma-facing components to withstand the high particle and power load produced by particles escaping from magnetic confinement, tungsten is projected to be the wall material of choice due to its favorable properties [2]. Spectral studies of ions of heavy elements provide data that are invaluable in a variety of fields including atomic physics, astronomy, and high-temperature plasma diagnostics [3]. Accurate atomic data including information on atomic transitions for a large range of charge states of tungsten are needed to develop diagnostics for measuring tungsten concentrations in fusion plasmas and to provide support for modeling [2].

Accurate atomic data for a large range of charge states of tungsten have been recently presented in literature. Kramida presented a study on recent progress in spectroscopy of tungsten [4]. A detailed analysis of extreme ultraviolet (EUV) spectra of highly charged tungsten ions W^{54+}–W^{63+} obtained with an electron beam ion trap was presented by Ralchenko et al. [5]. Energy levels, radiative transition probabilities and autoionization rates for some states in large range of highly ionized tungsten ions were calculated by Safronova et al. [6, 7]. The energy levels and spectral lines of multiply ionized tungsten atoms, W^{2+} through W^{73+}, were compiled by Kramida and Shirai [8]. Hu et al. presented a systematic MCDF study of the transition probabilities for some tungsten ions [1]. Clementson and Beiersdorfer measured wavelengths of $n = 3$ to $n = 3$ transitions in highly charged tungsten ions [9]. An overview of recent results from the Livermore WOLFRAM spectroscopy project is presented by Clementson et al. [10]. In Refs. [11–33] there can be found other previous works on Mg-like tungsten and other tungsten ions.

In this work, we have calculated energies and radiative transition (E1, E2, M1, and M2) parameters including the wavelengths, and transition probabilities for some low-lying levels in Mg-like tungsten (W^{62+}) using atomic structure code AUTOSTRUCTURE [34] developed by Badnell. Atomic radiative transition (especially, E1, E2, M1, and M2) is one of the fundamental processes in plasmas. The numerical simulation of atomic kinetics in laboratory as well as astrophysical plasmas requires accurate radiative transition rates (or probabilities) [35]. Although the atomic kinetics depend on, in particular, optical allowed transitions (E1) the weak forbidden transitions (E2, M1, and M2) are of great interest for the plasma diagnostics since the photons from such transitions may carry information from large optical depths within the plasma [1, 36].

2. Computations: AUTOSTRUCTURE

AUTOSTRUCTURE code [34] has been used in order to calculate energy levels, wavelengths and transition probabilities for E1, E2, M1, and M2 transitions in W^{62+}. Details on this code have been presented in a number of studies. We shall here give information briefly.

AUTOSTRUCTURE code [34, 37, 38] is a general program for the calculation of atomic and ionic energy levels, radiative and autoionization rates and photoionization cross-sections using non-relativistic or semi-relativistic wave functions. It is based on SUPERSTRUCTURE [39]. In this code, the configuration set is chosen optionally and there is added new configuration to improve accuracy (a configuration interaction expansion, CI expansion). The CI expansion is related to the choice of radial functions. Each (nl) radial function is calculated in Thomas–Fermi or Slater-type-orbital potential model. The Hamiltonian in any coupling model (LS, IC, or ICR) is diagonalized to obtain eigenvalues and eigenvectors with which to construct the rates. Detailed information on the method of this code can be found in [37–39].

Radiative properties of atoms are described with one electromagnetic transition between two states, character-

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ized by the angular momentum and parity of the corresponding photon [40]. If the emitted or absorbed photon has angular momentum k and parity $\pi = (-1)^k$, then the transition is an electric multipole transition (Ek). However, if the photon has parity $\pi = (-1)^{k+1}$ the transition is a magnetic multipole transition (Mk). Once initial and final state functions have been calculated, the radiative matrix element for radiative properties computation can be obtained. The transition rate (or probability) for the emission from the upper level to the lower level is given by

$$A^{\pi k}(\gamma' J', \gamma J) = 2C_k \left[\alpha \left(E_{\gamma' J'} - E_{\gamma J}\right)\right]^{2k+1} \frac{S^{\pi k}(\gamma' J', \gamma J)}{g_{J'}}, \quad (1)$$

where $S^{\pi k}$ is line strength,

$$S^{\pi k}(\gamma' J', \gamma J) = \left| \langle \gamma J || \boldsymbol{O}^{\pi(k)} || \gamma' J' \rangle \right|^2 . \quad (2)$$

$C_k = (2k+1)(k+1)/k((2k+1)!!)^2$, and $g_{J'}$ denotes statistical weight of the upper level, namely $g_{J'} = 2J' + 1$. In (2), $\boldsymbol{O}^{\pi(k)}$ is a transition operator and describes each multipole.

TABLE I

Configurations considered for calculations.

	Configurations
a	$2p^63s^2 + 2p^63s3p + 2p^63s3d + 2p^63s4s + 2p^63s4p + 2p^63s4d + 2p^63s4f + 2p^53s^23p + 2p^53s3p^2 + 2p^53p^3 + 2p^53s^23d + 2p^53s3p3d + 2p^53p^23d + 2p^53s3p4s + 2p^63p^2 + 2p^63p4s + 2p^64s^2 + 2p^64s4p$
b	$2p^63s^2 + 2p^63s3p + 2p^63s3d + 2p^63s4s + 2p^63s4p + 2p^63s4d + 2p^63s4f + 2p^63s5s + 2p^63s5p + 2p^63p^2 + 2p^63p3d + 2p^63p4s + 2p^63p4p + 2p^63d^2 + 2p^53s^23p + 2p^53s3p^2 + 2p^53p^3 + 2p^53s^23d + 2p^53s^24s + 2p^53s3p3d + 2p^53p^23d + 2p^53d^3 + 2p^53s3d^2 + 2p^53s3p4s + 2p^64s^2 + 2p^64s4p + 2p^64s4d$

We have here studied various configuration sets for considering correlation effects. These configuration sets are given in Table I. In AUTOSTRUCTURE calculation all of configurations with odd- and even-parity are studied together in order to obtain wave functions. We considered the Breit and quantum electrodynamics (QED) contributions in the calculation b whereas the Breit contribution is only taken in the calculation a. AUTOSTRUCTURE code includes configuration interaction calculations.

3. Results and discussion

We have presented the AUTOSTRUCTURE [34] studies on the level structure of Mg-like tungsten (W^{62+}). The excitation energies, wavelengths, and transition probabilities for allowed (E1) and forbidden (E2, M1, and M2) transitions have been calculated.

W^{62+} has an electronic structure with two electrons moving in the resultant field of the nucleus and the 10 inner electrons in ground state. It is well known that the correlation and relativistic effects are important for heavy ions ($Z = 74$ for tungsten) and the consideration of both intervalence and core-valence correlation is essential for atomic structure calculations of the atoms multiply ionized. In this study we have investigated the intervalence correlation where one or two valence orbitals are only excited and the core-valence correlation where one core orbital ($2p$ orbital in this work) and one valence orbitals are excited. In this framework, we considered increasingly the configuration sets for AUTOSTRUCTURE calculations as seen in Table I. The core $1s^22s^2$ and $1s^22s^22p^6$ is omitted in Table I and Tables II–IV (at the end), respectively. Also odd-parity levels is only indicated with superscript "o" in tables.

The excitation energies for W^{62+} including AUTOSTRUCTURE results have been reported and compared with other works available in Table II. The level energies are relative to the ground state $3s^2\ ^1S_0$. In AUTOSTRUCTURE calculation, we studied with two configuration sets denoted by the superscript a and b. 453 and 698 energy levels were obtained using the configuration set a and b, respectively. In Table II we have given some of them, in particular low-lying levels. It is seen that there is a good agreement between our AUTOSTRUCTURE results and others. Also our AUTOSTRUCTURE results in the calculation b include Breit and QED contributions whereas taking only QED contributions in the calculation a. Generally, the results from the calculation b are better. Hence we have given $\left(\frac{E_{\text{tw}} - E_{\text{ow}}}{E_{\text{ow}}}\right) \times 100$, the differences in percent for the calculation b of AUTOSTRUCTURE. E_{tw} and E_{ow} denote our results and other results (from [6]), respectively, in Table II. When the differences (%) between our results and other results (in [6]) are investigated, the differences are generally in range of 0.0028–4.33 for our AUTOSTRUCTURE calculation (except $3d^2$ levels). Generally, our results agree with other works, and the orderings of all levels are also the same, except some $3d^2$ levels.

Applying AUTOSTRUCTURE code the calculated wavelengths and transition probabilities (or rates) of electric-dipole allowed lines for low-lying levels of W^{62+} are listed in Table III. The results in the table are obtained from the calculation b of AUTOSTRUCTURE code. These results include correlation effects and Breit+QED for the calculation b and Breit–Pauli relativistic effects for a. We have obtained 60493 transitions from AUTOSTRUCTURE for electric dipole (E1) transitions among the 78 levels of W^{62+}. The results are listed in Table III where the transition probabilities under 10^5 s^{-1} are not given. Also the transition parameters for other transitions with high transition probabilities can be given as supplementary data by authors.

The forbidden transitions, i.e. electric quadrupole (E2), magnetic dipole (M1) and magnetic quadrupole (M2) radiations for low-lying levels are calculated. There are 198164 forbidden transitions (E2, M1, and M2 are calculated together) for AUTOSTRUCTURE calculations among 78 levels. The E2, M1, and M2 transitions obtained from $3s3p$ and $3p^2$ are given in Table IV. Again these transition parameters are calculated from the calculation *b* of AUTOSTRUCTURE. In the table, we give only the transition probabilities larger than 10^{-1} s^{-1} for forbidden transitions. There are a few data on E2, M1, and M2 forbidden transitions for Mg-like tungsten in available literature. Therefore, we have only compared the results obtained with other theoretical results [35].

In summary, the transition probabilities of optical allowed transitions (E1) and forbidden transitions (E2, M1, M2) are sensitive to electron correlation and relativistic effects. It is well known that the accurate radiative transition rates are required in particular, for astrophysical plasmas. In this paper we have presented results for energy levels and radiative probabilities for allowed and forbidden transitions (E1, E2, M1, and M2) among the lowest 78 levels of W^{62+}. Transition parameters in the literature for this ion are only available for a limited number of transitions. By applying the AUTOSTRUCTURE code, excitation energies and radiative parameters such as wavelengths and transition probabilities for E1, E2, M1, and M2 transitions are here calculated by considering the electron correlation and relativistic and quantum electrodynamic effects. Most of the transition data reported in the present work are new. We hope that these results will be helpful for the theoretical and experimental studies on the level structure of W^{62+}.

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TABLE II

Energies, E (10^3 cm^{-1}), for low-lying levels of W^{62+} calculated using AUTOSTRUCTURE code. The differences (%) by comparing our results with those obtained using HULLAC code in Ref. [6] are given**.

Index	Conf.	Level	This work	Diff. [%]	Other works
1	$3s^2$	$^1S_0$	0.00^a, 0.00^b	0.00	0.00^A, 0.00^B, 0.00^C
2	$3s3p$	$^3P_0^o$	1144.692^a, 1125.621^b	0.92	1149.816^A, 1126.449^B, 1136.079^C, 1126.000^D
3	$3s3p$	$^3P_1^o$	1283.045^a, 1257.904^b	0.76	1271.524^A, 1252.154^B, 1267.584^C, 1251.400^E
4	$3p^2$	$^3P_0$	2749.676^b	1.03	2706.827^A, 2687.591^B, 2721.583^C
5	$3s3p$	$^3P_2^o$	4100.475^a, 4099.002^b	0.25	4125.356^A, 4104.094^B, 4109.447^C, 4104.000^D
6	$3s3p$	$^1P_1^o$	4423.119^a, 4402.512^b	0.27	4399.741^A, 4402.930^B, 4414.698^C, 4398.500^F
7	$3p^2$	$^1D_2$	5565.492^b	0.15	5583.677^A, 5535.299^B, 5557.115^C
8	$3p^2$	$^3P_1$	5582.822^b	0.18	5585.086^A, 5551.449^B, 5572.679^C
9	$3s3d$	$^3D_1$	5829.144^a, 5832.468^b	0.17	5772.978^A, 5826.700^B, 5842.706^C, 5827.000^D
10	$3s3d$	$^3D_2$	5955.001^a, 5944.539^b	0.16	5862.612^A, 5930.433^B, 5954.313^C, 5930.400^F
11	$3s3d$	$^3D_3$	6525.342^a, 6528.353^b	0.20	6451.470^A, 6497.864^B, 6514.682^C, 6498.000^D
12	$3s3d$	$^1D_2$	6678.804^a, 6674.564^b	0.26	6551.650^A, 6638.292^B, 6656.792^C, 6638.000^D
13	$3p3d$	$^3F_2^o$	7148.790^b	1.07	7032.922^A, 7040.920^B, 7073.000^C
14	$3p3d$	$^3D_1^o$	7422.524^b	0.90	7268.523^A, 7319.021^B, 7355.779^C
15	$3p3d$	$^3P_2^o$	7984.399^b	1.17	7832.965^A, 7864.742^B, 7891.697^C
16	$3p3d$	$^3F_3^o$	8014.381^b	1.14	7860.956^A, 7888.737^B, 7923.446^C
17	$3p^2$	$^3P_2$	8615.405^a, 8594.622^b	0.15	8607.162^A, 8587.871^B, 8608.270^C
18	$3p^2$	$^1S_0^o$	8790.253^a, 8747.235^b	0.14	8743.883^A, 8742.077^B, 8760.103^C
19	$3p3d$	$^3D_2^o$	10148.980^b	0.0028	10089.709^A, 10123.675^B, 10148.690^C
20	$3p3d$	$^3P_0^o$	10225.013^b	0.0036	10155.694^A, 10204.774^B, 10225.388^C
21	$3p3d$	$^3P_1^o$	10233.224^b	0.019	10168.492^A, 10798.476^B, 10235.181^C
22	$3p3d$	$^1F_3^o$	10239.855^b	–	–
23	$3p3d$	$^3F_4^o$	10745.835^b	0.18	10675.321^A, 10703.303^B, 10725.535^C
24	$3p3d$	$^1D_2^o$	10837.167^b	–	–
25	$3p3d$	$^3D_3^o$	10999.262^b	0.19	10913.152^A, 10948.353^B, 10978.314^C
26	$3p3d$	$^1P_1^o$	11098.454^b	0.19	11000.873^A, 11050.425^B, 11076.381^C
27	$3d^2$	$^3F_2$	12299.524^b	4.21	11655.640^A, 11764.712^B, 11801.741^C
28	$3d^2$	$^3P_0^o$	12501.277^b	4.06	11830.419^A, 11979.693^B, 12012.701^C
29	$3d^2$	$^3F_3$	12969.404^b	4.32	12301.781^A, 12403.203^B, 12432.187^C
30	$3d^2$	$^3P_2$	13059.911^b	4.21	12383.832^A, 12501.277^B, 12531.285^C
31	$3d^2$	$^3P_1$	13098.060^b	4.22	12413.004^A, 12545.045^B, 12567.072^C
32	$3d^2$	$^1G_4$	13098.941^b	4.28	12411.383^A, 12518.342^B, 12560.665^C
33	$3d^2$	$^3F_4$	13715.884^b	4.33	13012.810^A, 13114.392^B, 13146.237^C
34	$3d^2$	$^1D_2$	13787.690^b	4.26	13077.950^A, 13198.696^B, 13224.202^C
35	$3d^2$	$^1S_0$	14015.637^b	4.18	13265.374^A, 13431.171^B, 13452.476^C
36	$3s4s$	$^3S_1$	25860.420^a, 25857.151^b	–	–
37	$3s4s$	$^1S_0$	25982.673^a, 25971.254^b	–	–
38	$3s4p$	$^3P_0^o$	26996.125^a, 26973.553^b	–	–
39	$3s4p$	$^3P_1^o$	27011.730^a, 26989.378^b	–	–
40	$3p4s$	$^3P_1^o$	27580.528^a, 27591.079^b	–	–
41	$3p4s$	$^3P_0^o$	27592.639^a, 27602.977^b	–	–
42	$3p4p$	$^3D_1$	28131.172^b	–	–
43	$3s4p$	$^3P_2^o$	28183.900^a, 28181.576^b	1.98	27609.237^A, 27619.457^B, 27632.906^C
44	$3s4p$	$^1P_1^o$	28235.382^a, 28232.409^b	1.97	27655.303^A, 27669.012^B, 27685.514^C
45	$3p4p$	$^3P_0$	28418.984^b	–	–
46	$3s4d$	$^3D_2$	28828.714^a, 28824.793^b	–	–
47	$3s4d$	$^3D_1$	28818.781^a, 28830.123^b	1.96	28221.172^A, 28258.189^B, 28275.011^C
48	$3s4d$	$^1D_2$	29133.008^a, 29101.164^b	–	–
49	$3s4d$	$^3D_3$	29112.962^a, 29111.339^b	–	–
50	$3p4p$	$^3P_1$	29451.550^b	1.69	28940.576^A, 28932.956^B, 28961.942^C
51	$3s4f$	$^3F_2^o$	29480.744^a, 29483.044^b	–	–
52	$3p4p$	$^1D_2$	29492.808^b	–	–
53	$3s4f$	$^3F_3^o$	29501.674^a, 29504.650^b	–	–
54	$3s4f$	$^3F_4^o$	29604.817^a, 29607.199^b	1.96	28987.756^A, 29021.055^B, 29037.236^C
55	$3s4f$	$^1F_3^o$	29660.632^a, 29665.365^b	–	–

TABLE II (cont.)

Index	Conf.	Level	This work	Diff. [%]	Other works
56	$3p4s$	$^3P_2^o$	30676.717^a, 30684.524^b	1.65	30165.147^A, 30166.779^B, 30185.574^C
57	$3p4s$	$^1P_1^o$	30719.749^a, 30727.180^b	1.66	30198.927^A, 30203.000^B, 30224.279^C
58	$3p4p$	$^3S_1$	31282.397^b	–	–
59	$3p4p$	$^3D_2$	31297.067^b	–	–
60	$3p4p$	$^1P_1$	32410.547^b	–	–
61	$3p4p$	$^3D_3$	32411.043^b	–	–
62	$3p4p$	$^3P_2$	32527.476^b	1.62	31975.334^A, 31979.937^B, 32007.034^C
63	$3p4p$	$^1S_0$	32640.801^b	–	–
64	$3s5s$	$^3S_1$	37883.518^b	–	–
65	$3s5s$	$^1S_0$	37927.573^b	–	–
66	$3s5p$	$^3P_0^o$	38200.496^b	–	–
67	$3s5p$	$^3P_1^o$	38205.002^b	–	–
68	$3s5p$	$^3P_2^o$	38783.854^b	–	–
69	$3s5p$	$^1P_1^o$	38797.436^b	–	–
70	$4s^2$	$^1S_0$	52581.775^a, 52584.369^b	–	–
71	$4s4p$	$^3P_0^o$	53035.945^a, 53040.889^b	–	–
72	$4s4p$	$^3P_1^o$	53109.942^a, 53114.895^b	–	–
73	$4s4p$	$^3P_2^o$	54206.736^a, 54211.481^b	–	–
74	$4s4p$	$^1P_1^o$	54389.103^a, 54393.915^b	–	–
75	$4s4d$	$^3D_1$	54886.735^b	–	–
76	$4s4d$	$^3D_2$	54921.585^b	–	–
77	$4s4d$	$^3D_3$	55187.942^b	–	–
78	$4s4d$	$^1D_2$	55263.257^b	–	–

^{A} Cowan code, ^{B} RMBPT code, ^{C} HULLAC code in Ref. [6], ^{D} Ref. [10], ^{E} Ref. [5], ^{F} Ref. [9],
** $\left(\frac{E_{\rm tw}-E_{\rm ow}}{E_{\rm ow}}\right)\times 100$, where tw and ow are This work and Other works data, repectively.

TABLE III

Transition probabilities, A_{ki} [s^{-1}], wavelengths, λ[], of allowed lines (E1) in W^{62+} calculated using the AUTOSTRUCTURE code. In table, $a(b)$ denotes $a\times 10^b$. U and L indicate upper and lower level, respectively.

Transitions		A_{ki} [s^{-1}]		λ [Å]	
U	L	This work	Other works	This work	Other works
$3s3p\ ^3P_1^o$	$3s^2\ ^1S_0$	1.89(10)	$1.80(10)^B$, $2.67(10)^C$, $2.14(10)^D$ $1.82(10)^E$, $1.81(10)^H$, $1.81(10)^I$	79.497	79.86^B, 78.89^C, 78.73^D 79.90^E, 79.91^F 79.91^G, 79.94^H
$3p^2\ ^3P_0$	$3s3p\ ^3P_1^o$	1.50(11)	$1.28(11)^A$	67.034	69.665^A
$3s3p\ ^1P_1^o$	$3s^2\ ^1S_0$	2.58(12)	$2.57(12)^A$, $2.57(12)^B$, $3.28(12)^C$ $2.59(12)^D$, $2.55(12)^H$, $2.57(12)^I$	22.714	22.712^A, 22.71^B, 22.65^C 22.73^D, 22.80^G, 22.74^H
$3s3p\ ^1P_1^o$	$3p^2\ ^3P_0$	5.54(08)	–	60.502	–
$3p^2\ ^1D_2$	$3s3p\ ^3P_1^o$	4.76(11)	$4.72(11)^A$	23.214	23.347^A
$3p^2\ ^1D_2$	$3s3p\ ^3P_2^o$	3.57(10)	$3.17(10)^B$, $3.61(10)^C$, $3.57(10)^D$	68.190	69.87^B, 69.07^C, 69.17^D
$3p^2\ ^1D_2$	$3s3p\ ^1P_1^o$	9.01(09)	–	85.987	–
$3p^2\ ^3P_1$	$3s3p\ ^3P_0^o$	1.24(12)	$1.20(12)^A$, $1.20(12)^B$ $1.29(12)^C$, $1.27(12)^D$	22.436	22.599^A, 22.60^B 22.54^C, 22.52^D
$3p^2\ ^3P_1$	$3s3p\ ^3P_1^o$	6.53(11)	$6.50(11)^A$, $6.50(11)^B$ $5.90(11)^C$, $6.39(11)^D$	23.122	23.260^A, 23.26^B 23.23^C, 23.15^D
$3p^2\ ^3P_1$	$3s3p\ ^3P_2^o$	5.50(10)	–	67.394	–
$3p^2\ ^3P_1$	$3s3p\ ^1P_1^o$	4.45(09)	–	84.724	–
$3s3d\ ^3D_1$	$3s3p\ ^3P_0^o$	1.11(12)	$1.09(12)^A$, $1.09(12)^B$ $1.16(12)^C$, $1.05(12)^D$	21.246	21.275^A, 21.28^B 21.25^C, 21.63^D
$3s3d\ ^3D_1$	$3s3p\ ^3P_1^o$	5.29(11)	$5.03(11)^A$, $5.03(11)^B$ $4.62(11)^C$, $5.30(11)^D$	21.860	21.860^A, 21.86^B 21.86^C, 22.21^D
$3s3d\ ^3D_1$	$3s3p\ ^3P_2^o$	2.31(09)	–	57.688	–
$3s3d\ ^3D_1$	$3s3p\ ^1P_1^o$	5.34(09)	–	69.932	–

TABLE III (cont.)

Transitions		A_{ki} [s^{-1}]		λ [Å]	
U	L	This work	Other works	This work	Other works
$3s3d\ ^3D_2$	$3s3p\ ^3P_1^o$	2.78(12)	2.73(12)[A], 2.73(12)[B]	21.337	21.375[A], 21.38[B]
			2.81(12)[C], 2.82(12)[D]		21.34[C], 21.69[D]
$3s3d\ ^3D_2$	$3s3p\ ^3P_2^o$	8.67(08)	–	54.185	–
$3s3d\ ^3D_2$	$3s3p\ ^1P_1^o$	3.04(09)	–	64.850	–
$3s3d\ ^3D_3$	$3s3p\ ^3P_2^o$	2.60(11)	2.48(11)[A], 2.48(11)[B]	41.163	41.775[A], 41.78[B]
			2.52(11)[C], 2.33(11)[D]		41.58[C], 42.97[D]
$3s3d\ ^1D_2$	$3s3p\ ^3P_1^o$	2.08(11)	2.15(11)[A]	18.462	18.566[A]
$3s3d\ ^1D_2$	$3s3p\ ^3P_2^o$	7.82(10)	7.32(10)[B], 7.89(10)[C], 6.73(10)[D]	38.827	39.46[B], 39.26[C], 40.73[D]
$3s3d\ ^1D_2$	$3s3p\ ^1P_1^o$	2.13(11)	2.02(11)[A]	44.013	44.735[A]
$3p3d\ ^3F_2^o$	$3p^2\ ^1D_2$	3.22(10)	–	63.159	–
$3p3d\ ^3F_2^o$	$3p^2\ ^3P_1$	1.20(09)	–	63.858	–
$3p3d\ ^3F_2^o$	$3s3d\ ^3D_1$	2.53(10)	–	75.969	–
$3p3d\ ^3F_2^o$	$3s3d\ ^3D_2$	9.75(09)	–	83.039	–
$3p3d\ ^3F_2^o$	$3s3d\ ^3D_3$	1.38(05)	–	161.177	–
$3p3d\ ^3F_2^o$	$3s3d\ ^1D_2$	3.82(06)	–	210.870	–
$3p3d\ ^3D_1^o$	$3s^2\ ^1S_0$	7.02(07)	–	13.473	–
$3p3d\ ^3D_1^o$	$3p^2\ ^3P_0$	2.25(12)	–	21.400	–
$3p3d\ ^3D_1^o$	$3p^2\ ^1D_2$	5.20(09)	–	53.849	–
$3p3d\ ^3D_1^o$	$3p^2\ ^3P_1$	1.83(10)	1.32(12)[A], 1.59(10)[B]	54.357	21.471[A], 56.57[B]
			1.57(10)[C], 1.37(10)[D]		56.08[C], 59.68[D]
$3p3d\ ^3D_1^o$	$3s3d\ ^3D_1$	1.55(10)	1.49(12)[A]	62.891	22.819[A]
$3p3d\ ^3D_1^o$	$3s3d\ ^3D_2$	6.10(10)	5.22(11)[A]	67.660	23.372[A]
$3p3d\ ^3D_1^o$	$3s3d\ ^1D_2$	2.82(08)	–	133.697	–
$3p3d\ ^3P_2^o$	$3p^2\ ^1D_2$	3.87(10)	1.45(12)[A]	41.341	21.794[A]
$3p3d\ ^3P_2^o$	$3p^2\ ^3P_1$	2.33(11)	7.20(11)[A], 2.08(11)[B]	41.639	21.871[A], 43.23[B]
			2.22(11)[C], 1.94(11)[D]		43.12[C], 44.62[D]
$3p3d\ ^3P_2^o$	$3s3d\ ^3D_1$	4.44(06)	8.76(11)[A]	46.470	23.272[A]
$3p3d\ ^3P_2^o$	$3s3d\ ^3D_2$	7.12(09)	2.57(11)[A]	49.023	23.848[A]
$3p3d\ ^3P_2^o$	$3s3d\ ^3D_3$	5.56(10)	4.20(10)[B], 4.33(10)[C], 4.70(10)[D]	68.679	73.16[B], 72.62[C], 72.49[D]
			4.31(11)[&], 4.39(11)[+], 4.33(11)[*]		23.25[&], 23.23[+], 23.20[*]
$3p3d\ ^3P_2^o$	$3s3d\ ^1D_2$	8.35(09)	–	76.346	–
$3p3d\ ^3F_3^o$	$3p^2\ ^1D_2$	1.62(11)	1.45(11)[A], 3.58(11)[B]	40.835	42.491[A], 21.41[B]
			3.79(11)[C], 2.94(11)[D]		21.36[C], 21.75[D]
$3p3d\ ^3F_3^o$	$3s3d\ ^3D_2$	1.82(09)	–	48.313	–
$3p3d\ ^3F_3^o$	$3s3d\ ^3D_3$	3.35(10)	2.52(10)[B], 2.62(10)[C], 2.82(10)[D]	67.294	71.90[B], 70.98[C], 71.13[D]
			3.16(10)[&], 3.20(10)[+], 2.72(10)[*]		26.97[&], 26.85[+], 26.91[*]
$3p3d\ ^3F_3^o$	$3s3d\ ^1D_2$	3.92(10)	–	74.637	–
$3p^2\ ^3P_2$	$3s3p\ ^3P_1^o$	1.66(08)	–	13.630	–
$3p^2\ ^3P_2$	$3s3p\ ^3P_2^o$	1.83(12)	1.82(12)[A]	22.244	22.303[A]
$3p^2\ ^3P_2$	$3s3p\ ^1P_1^o$	1.86(12)	1.84(12)[A]	23.854,	23.895[A]
$3p^2\ ^3P_2$	$3p3d\ ^3F_2^o$	5.25(07)	–	69.164	–
$3p^2\ ^3P_2$	$3p3d\ ^3D_1^o$	2.11(08)	–	85.317	–
$3p^2\ ^3P_2$	$3p3d\ ^3P_2^o$	7.93(06)	–	163.875	–
$3p^2\ ^3P_2$	$3p3d\ ^3F_3^o$	5.70(06)	–	172.343	–
$3p^2\ ^1S_0$	$3s3p\ ^3P_1^o$	1.28(10)	–	13.352	–
$3p^2\ ^1S_0$	$3s3p\ ^1P_1^o$	3.59(12)	3.57(12)[A]	23.016	23.046[A]
$3p^2\ ^1S_0$	$3p3d\ ^3D_1^o$	4.32(06)	–	75.488	–
$3p3d\ ^3D_2^o$	$3p^2\ ^1D_2$	1.49(12)	1.45(12)[B], 1.55(12)[C], 1.48(12)[D]	21.817	21.79[B], 21.78[C], 22.14[D]
$3p3d\ ^3D_2^o$	$3p^2\ ^3P_1$	7.75(11)	7.20(11)[B], 7.85(11)[C], 7.52(11)[D]	21.900	21.87[B], 21.85[C], 22.23[D]
$3p3d\ ^3D_2^o$	$3s3d\ ^3D_1$	8.71(11)	–	23.167	–
$3p3d\ ^3D_2^o$	$3s3d\ ^3D_2$	2.53(11)	–	23.784	–
$3p3d\ ^3D_2^o$	$3s3d\ ^3D_3$	2.92(09)	4.31(11)[A], 3.10(09)[B]	27.620	23.253[A], 27.58[B]
			3.07(09)[C], 2.73(09)[D]		27.52[C], 27.50[D]

TABLE III (cont.)

Transitions		A_{ki} [s^{-1}]		λ [Å]	
U	L	This work	Other works	This work	Other works
$3p3d\ ^3D_2^o$	$3s3d\ ^1D_2$	7.71(08)	1.35(12)^A	28.782	24.037^A
$3p3d\ ^3D_2^o$	$3p^2\ ^3P_2$	7.22(09)	1.23(11)^A	64.335	45.236^A
$3p3d\ ^3P_0^o$	$3p^2\ ^3P_1$	1.58(12)	1.47(12)^A	21.542	21.490^A
$3p3d\ ^3P_0^o$	$3s3d\ ^3D_1$	1.97(12)	1.98(12)^A	22.766	22.841^A
$3p3d\ ^3P_1^o$	$3s^2\ ^1S_0$	1.92(08)	–	9.772	–
$3p3d\ ^3P_1^o$	$3p^2\ ^3P_0$	1.28(09)	2.08(12)^A	13.363	21.592^A
$3p3d\ ^3P_1^o$	$3p^2\ ^1D_2$	5.52(10)	–	21.424	–
$3p3d\ ^3P_1^o$	$3p^2\ ^3P_1$	1.37(12)	1.32(12)^B, 1.34(12)^C, 1.26(12)^D	21.504	21.47^B, 21.45^C, 21.85^D
$3p3d\ ^3P_1^o$	$3s3d\ ^3D_1$	1.52(12)	–	22.723	–
$3p3d\ ^3P_1^o$	$3s3d\ ^3D_2$	5.40(11)	–	23.317	–
$3p3d\ ^3P_1^o$	$3s3d\ ^1D_2$	9.27(09)	–	28.101	–
$3p3d\ ^3P_1^o$	$3p^2\ ^3P_2$	1.33(10)	–	61.028	–
$3p3d\ ^3P_1^o$	$3p^2\ ^1S_0$	4.14(09)	–	67.295	–
$3p3d\ ^1F_3^o$	$3p^2\ ^1D_2$	4.15(11)	–	21.393	–
$3p3d\ ^1F_3^o$	$3s3d\ ^3D_2$	2.64(12)	–	23.281	–
$3p3d\ ^1F_3^o$	$3s3d\ ^3D_3$	3.32(10)	9.90(11)^A	26.943	22.469^A
$3p3d\ ^1F_3^o$	$3s3d\ ^1D_2$	6.81(10)	6.50(11)^A	28.048	23.202^A
$3p3d\ ^1F_3^o$	$3p^2\ ^3P_2$	1.32(09)	4.41(11)^A	60.782	42.364^A
$3p3d\ ^3F_4^o$	$3s3d\ ^3D_3$	1.62(12)	1.62(12)^A, 1.62(12)^B	23.711	23.779^A, 23.78^B
			1.65(12)^C, 1.65(12)^D		23.75^C, 23.69^D
$3p3d\ ^1D_2^o$	$3p^2\ ^1D_2$	1.74(09)	–	18.969	–
$3p3d\ ^1D_2^o$	$3p^2\ ^3P_1$	4.02(09)	2.08(11)^A	19.032	43.228^A
$3p3d\ ^1D_2^o$	$3s3d\ ^3D_1$	9.87(09)	–	19.981	–
$3p3d\ ^1D_2^o$	$3s3d\ ^3D_2$	8.90(10)	–	20.439	–
$3p3d\ ^1D_2^o$	$3s3d\ ^3D_3$	4.36(11)	–	23.208	–
$3p3d\ ^1D_2^o$	$3s3d\ ^1D_2$	1.36(12)	–	24.023	–
$3p3d\ ^1D_2^o$	$3p^2\ ^3P_2$	1.29(11)	–	44.592	–
$3p3d\ ^3D_3^o$	$3p^2\ ^1D_2$	7.72(07)	3.58(11)^A	18.403	21.412^A
$3p3d\ ^3D_3^o$	$3s3d\ ^3D_2$	6.20(08)	2.59(12)^A	19.784	23.391^A
$3p3d\ ^3D_3^o$	$3s3d\ ^3D_3$	9.89(11)	–	22.367	–
$3p3d\ ^3D_3^o$	$3s3d\ ^1D_2$	6.53(11)	–	23.123	–
$3p3d\ ^3D_3^o$	$3p^2\ ^3P_2$	4.72(11)	–	41.586	–
$3p3d\ ^1P_1^o$	$3s^2\ ^1S_0$	1.40(10)	–	9.010	–
$3p3d\ ^1P_1^o$	$3p^2\ ^3P_0$	4.19(09)	–	11.978	–
$3p3d\ ^1P_1^o$	$3p^2\ ^1D_2$	3.29(10)	–	18.074	–
$3p3d\ ^1P_1^o$	$3p^2\ ^3P_1$	4.53(09)	–	18.130	–
$3p3d\ ^1P_1^o$	$3s3d\ ^3D_1$	4.43(09)	–	18.990	–
$3p3d\ ^1P_1^o$	$3s3d\ ^3D_2$	5.20(10)	–	19.403	–
$3p3d\ ^1P_1^o$	$3s3d\ ^1D_2$	1.89(12)	1.85(12)^A	22.605	22.665^A
$3p3d\ ^1P_1^o$	$3p^2\ ^3P_2$	4.97(10)	–	39.939	–
$3p3d\ ^1P_1^o$	$3p^2\ ^1S_0$	2.53(11)	2.35(11)^A	42.531	43.321^A
$3d^2\ ^3F_2$	$3s3p\ ^3P_1^o$	5.52(07)	–	9.057	–
$3d^2\ ^3F_2$	$3s3p\ ^3P_2^o$	2.11(08)	–	12.194	–
$3d^2\ ^3F_2$	$3s3p\ ^1P_1^o$	1.70(09)	–	12.663	–
$3d^2\ ^3F_2$	$3p3d\ ^3F_2^o$	2.17(12)	1.62(12)^A	19.415	21.169^A
$3d^2\ ^3F_2$	$3p3d\ ^3D_1^o$	1.92(12)	–	20.505	–
$3d^2\ ^3F_2$	$3p3d\ ^3P_2^o$	3.22(09)	–	23.174	–
$3d^2\ ^3F_2$	$3p3d\ ^3F_3^o$	1.03(09)	–	23.336	–
$3d^2\ ^3F_2$	$3p3d\ ^3D_2^o$	2.15(10)	–	46.500	–
$3d^2\ ^3F_2$	$3p3d\ ^3P_1^o$	2.17(10)	2.30(12)^A	48.396	22.494^A
$3d^2\ ^3F_2$	$3p3d\ ^1F_3^o$	1.68(10)	–	48.552	–
$3d^2\ ^3F_2$	$3p3d\ ^1D_2^o$	1.78(08)	–	68.383	–
$3d^2\ ^3F_2$	$3p3d\ ^3D_3^o$	2.92(08)	–	76.908	–
$3d^2\ ^3F_2$	$3p3d\ ^1P_1^o$	2.05(06)	–	83.259	–

TABLE III(cont.)

Transitions		A_{ki}[s^{-1}]		λ[Å]	
U	L	This work	Other works	This work	Other works
$3d^2\ {}^3P_0$	$3s3p\ {}^3P_1^o$	3.60(08)	–	8.894	–
$3d^2\ {}^3P_0$	$3s3p\ {}^1P_1^o$	7.63(06)	–	12.348	–
$3d^2\ {}^3P_0$	$3p3d\ {}^3D_1^o$	4.49(12)	–	19.690	–
$3d^2\ {}^3P_0$	$3p3d\ {}^3P_1^o$	8.47(10)	3.30(12)^A	44.091	21.456^A
$3d^2\ {}^3P_0$	$3p3d\ {}^1P_1^o$	1.56(06)	–	71.285	–
$3d^2\ {}^3F_3$	$3s3p\ {}^3P_2^o$	4.35(08)	–	11.273	–
$3d^2\ {}^3F_3$	$3p3d\ {}^3F_2^o$	4.18(08)	–	17.180	–
$3d^2\ {}^3F_3$	$3p3d\ {}^3P_2^o$	8.51(11)	1.74(11)^A	20.060	43.869^A
$3d^2\ {}^3F_3$	$3p3d\ {}^3F_3^o$	1.22(12)	8.84(11)	20.182	22.151^A
$3d^2\ {}^3F_3$	$3p3d\ {}^3D_2^o$	3.36(11)	–	35.456	–
$3d^2\ {}^3F_3$	$3p3d\ {}^1F_3^o$	4.86(10)	–	36.636	–
$3d^2\ {}^3F_3$	$3p3d\ {}^3F_4^o$	1.14(10)	4.88(09)^B, 4.88(09)^C, 4.58(09)^D	44.973	58.83^B, 58.59^C, 61.19^D
$3d^2\ {}^3F_3$	$3p3d\ {}^1D_2^o$	2.02(10)	6.10(11)^A	46.899	22.034^A
$3d^2\ {}^3F_3$	$3p3d\ {}^3D_3^o$	9.70(09)	–	50.758	–
$3d^2\ {}^3P_2$	$3s3p\ {}^3P_1^o$	4.49(09)	–	8.473	–
$3d^2\ {}^3P_2$	$3s3p\ {}^3P_2^o$	1.36(06)	–	11.160	–
$3d^2\ {}^3P_2$	$3s3p\ {}^1P_1^o$	1.01(07)	–	11.551	–
$3d^2\ {}^3P_2$	$3p3d\ {}^3F_2^o$	1.16(10)	–	16.917	–
$3d^2\ {}^3P_2$	$3p3d\ {}^3D_1^o$	6.87(09)	2.21(11)^A	17.739	43.624^A
$3d^2\ {}^3P_2$	$3p3d\ {}^3P_2^o$	1.68(12)	–	19.702	–
$3d^2\ {}^3P_2$	$3p3d\ {}^3F_3^o$	5.13(11)	3.72(11)^A	19.820	21.680^A
$3d^2\ {}^3P_2$	$3p3d\ {}^3D_2^o$	1.73(11)	–	34.353	–
$3d^2\ {}^3P_2$	$3p3d\ {}^3P_1^o$	2.54(11)	–	35.377	–
$3d^2\ {}^3P_2$	$3p3d\ {}^1F_3^o$	3.25(10)	–	35.460	–
$3d^2\ {}^3P_2$	$3p3d\ {}^1D_2^o$	2.31(09)	1.23(12)^A	44.989	21.568^A
$3d^2\ {}^3P_2$	$3p3d\ {}^3D_3^o$	1.06(10)	4.16(09)^B, 3.42(09)^C, 4.13(09)^D	48.528	64.39^B, 64.39^C, 67.34^D
$3d^2\ {}^3P_2$	$3p3d\ {}^1P_1^o$	1.71(10)	–	50.983	–
$3d^2\ {}^3P_1$	$3s3p\ {}^3P_0^o$	2.49(09)	–	8.353	–
$3d^2\ {}^3P_1$	$3s3p\ {}^3P_1^o$	1.29(09)	–	8.446	–
$3d^2\ {}^3P_1$	$3s3p\ {}^3P_2^o$	2.64(08)	–	11.112	–
$3d^2\ {}^3P_1$	$3s3p\ {}^1P_1^o$	6.24(07)	–	11.500	–
$3d^2\ {}^3P_1$	$3p3d\ {}^3F_2^o$	4.60(07)	–	16.809	–
$3d^2\ {}^3P_1$	$3p3d\ {}^3D_1^o$	4.66(08)	1.20(11)^A	17.620	42.807^A
$3d^2\ {}^3P_1$	$3p3d\ {}^3P_2^o$	2.25(12)	–	19.556	–
$3d^2\ {}^3P_1$	$3p3d\ {}^3D_2^o$	4.23(10)	–	33.909	–
$3d^2\ {}^3P_1$	$3p3d\ {}^3P_0^o$	2.38(11)	8.30(11)^A	34.806	22.841^A
$3d^2\ {}^3P_1$	$3p3d\ {}^3P_1^o$	2.26(11)	–	34.906	–
$3d^2\ {}^3P_1$	$3p3d\ {}^1D_2^o$	2.48(10)	1.65(12)^A	44.230	21.366^A
$3d^2\ {}^3P_1$	$3p3d\ {}^1P_1^o$	4.80(09)	–	50.010	–
$3d^2\ {}^1G_4$	$3p3d\ {}^3F_3^o$	1.70(12)	–	19.667	–
$3d^2\ {}^1G_4$	$3p3d\ {}^1F_3^o$	4.88(11)	2.98(11)^A	34.976	46.167^A
$3d^2\ {}^1G_4$	$3p3d\ {}^3F_4^o$	4.77(10)	1.18(11)^A, 2.09(10)^B 2.14(10)^C, 1.86(10)^D	42.497	41.475^A, 55.10^B 54.49^C, 57.24^D
$3d^2\ {}^1G_4$	$3p3d\ {}^3D_3^o$	1.05(10)	–	47.626	–
$3d^2\ {}^3F_4$	$3p3d\ {}^3F_3^o$	1.85(10)	1.21(12)^A	17.539	21.600^A
$3d^2\ {}^3F_4$	$3p3d\ {}^1F_3^o$	4.05(09)	–	28.769	–
$3d^2\ {}^3F_4$	$3p3d\ {}^3F_4^o$	2.20(11)	1.18(11)^B, 1.19(11)^C, 1.13(11)^D	33.670	41.48^B, 41.31^C, 42.61^D
$3d^2\ {}^3F_4$	$3p3d\ {}^3D_3^o$	6.02(11)	2.52(11)^A	36.810	43.237^A
$3d^2\ {}^1D_2$	$3s3p\ {}^3P_1^o$	7.46(08)	–	7.981	–
$3d^2\ {}^1D_2$	$3s3p\ {}^3P_2^o$	4.55(09)	–	10.321	–
$3d^2\ {}^1D_2$	$3s3p\ {}^1P_1^o$	6.93(09)	–	10.655	–
$3d^2\ {}^1D_2$	$3p3d\ {}^3F_2^o$	1.48(09)	–	15.063	–
$3d^2\ {}^1D_2$	$3p3d\ {}^3D_1^o$	4.95(07)	–	15.711	–
$3d^2\ {}^1D_2$	$3p3d\ {}^3P_2^o$	8.23(07)	–	17.232	–
$3d^2\ {}^1D_2$	$3p3d\ {}^3F_3^o$	9.87(07)	–	17.321	–

TABLE III(cont.)

Transitions		A_{ki}[s^{-1}]		λ[Å]	
U	L	This work	Other works	This work	Other works
$3d^2\ ^1D_2$	$3p3d\ ^3D_2^o$	5.14(09)	3.26(11)^A	27.482	41.663^A
$3d^2\ ^1D_2$	$3p3d\ ^3P_1^o$	5.65(09)	–	28.134	–
$3d^2\ ^1D_2$	$3p3d\ ^1F_3^o$	2.88(09)	–	28.186	–
$3d^2\ ^1D_2$	$3p3d\ ^1D_2^o$	6.12(11)	–	33.892	–
$3d^2\ ^1D_2$	$3p3d\ ^3D_3^o$	1.30(11)	–	35.863	–
$3d^2\ ^1D_2$	$3p3d\ ^1P_1^o$	2.16(11)	1.79(11)^A	37.185	46.549^A
$3d^2\ ^1S_0$	$3s3p\ ^3P_1^o$	4.71(09)	–	7.838	–
$3d^2\ ^1S_0$	$3s3p\ ^1P_1^o$	5.71(10)	–	10.402	–
$3d^2\ ^1S_0$	$3p3d\ ^3D_1^o$	6.03(10)	–	15.167	–
$3d^2\ ^1S_0$	$3p3d\ ^3P_1^o$	1.29(07)	–	26.438	–
$3d^2\ ^1S_0$	$3p3d\ ^1P_1^o$	1.13(12)	6.03(11)^A	34.280	42.004^A

^{A} Ref. [7], $^{B,\ C,\ D}$ Ref. [6], $^{E,\ F}$ Ref. [5], ^{G} Ref. [8], ^{H} Ref. [1], ^{I} Ref. [35], $^{\&,\ +,\ *}$ in Ref. [6].

TABLE IV

Transition probabilities, A_{ki} [s^{-1}] and wavelengths, λ [Å] of forbidden lines (E2, M1, and M2). In table, $a(b)$ denotes $a \times 10^b$. U and L indicate upper and lower levels, respectively.

Transitions		Transition	A_{ki} [s^{-1}]		λ [Å]
U	L	type	This work	Other works	This work
$3s3p\ ^3P_1^o$	$3s3p\ ^3P_0^o$	M1	3.03(04)	2.60(04)^A	755.95
$3s3p\ ^3P_2^o$	$3s3p\ ^3P_0^o$	E2	2.95(06)	2.91(06)^A	33.63
$3s3p\ ^3P_2^o$	$3s3p\ ^3P_1^o$	E2	3.88(06)	3.86(06)^A	35.20
		M1	2.22(08)	2.19(08)^A	–
$3s3p\ ^1P_1^o$	$3s3p\ ^3P_0^o$	M1	1.70(08)	1.67(08)^A	30.52
$3s3p\ ^1P_1^o$	$3s3p\ ^3P_1^o$	E2	7.15(06)	7.10(06)^A	31.80
		M1	8.21(07)	8.13(07)^A	
$3s3p\ ^1P_1^o$	$3s3p\ ^3P_2$	E2	3.71(01)	3.49(01)^A	329.48
		M1	1.71(05)	1.63(05)^A	–
$3p^2\ ^1D_2$	$3p^2\ ^3P_0$	E2	3.06(06)	–	35.51
$3p^2\ ^3P_1$	$3p^2\ ^3P_0$	M1	2.79(08)	–	35.30
$3p^2\ ^3P_1$	$3p^2\ ^1D_2$	E2	2.09(05)	–	5770.27
		M1	3.20(01)	–	–
$3p^2\ ^3P_2$	$3p^2\ ^3P_0$	E2	9.77(03)	–	17.11
$3p^2\ ^3P_2$	$3p^2\ ^1D_2$	E2	8.67(06)	–	33.01
		M1	1.89(08)	–	–
$3p^2\ ^3P_2$	$3p^2\ ^3P_1$	E2	4.24(06)	–	33.20
		M1	2.31(08)	–	–
$3p^2\ ^1S_0$	$3p^2\ ^1D_2$	E2	1.68(07)	–	31.43
$3p^2\ ^1S_0$	$3p^2\ ^3P_1$	M1	5.22(08)	–	31.60
$3p^2\ ^1S_0$	$3p^2\ ^3P_2$	E2	1.13(01)	–	655.25
$3p^2\ ^1D_2$	$3s3p\ ^3P_1^o$	M2	1.55(05)	–	23.21
$3p^2\ ^1D_2$	$3s3p\ ^3P_2^o$	M2	1.28(02)	–	68.19
$3p^2\ ^1D_2$	$3s3p\ ^1P_1^o$	M2	1.74(02)	–	85.99
$3p^2\ ^3P_1$	$3s3p\ ^3P_1^o$	M2	5.05(04)	–	23.12
$3p^2\ ^3P_1$	$3s3p\ ^3P_2^o$	M2	7.53(−01)	–	67.39
$3p^2\ ^3P_1$	$3s3p\ ^1P_1^o$	M2	4.64(02)	–	84.72
$3p^2\ ^3P_2$	$3s3p\ ^3P_0^o$	M2	2.72(02)	–	13.39
$3p^2\ ^3P_2$	$3s3p\ ^3P_1^o$	M2	2.42(06)	–	13.63
$3p^2\ ^3P_2$	$3s3p\ ^3P_2^o$	M2	5.67(05)	–	22.24
$3p^2\ ^3P_2$	$3s3p\ ^1P_1^o$	M2	2.84(04)	–	23.85
$3p^2\ ^1S_0$	$3s3p\ ^3P_2^o$	M2	9.89(05)	–	21.51

^{A} Ref. [35].